

Mean field studies for the Pt isotopes

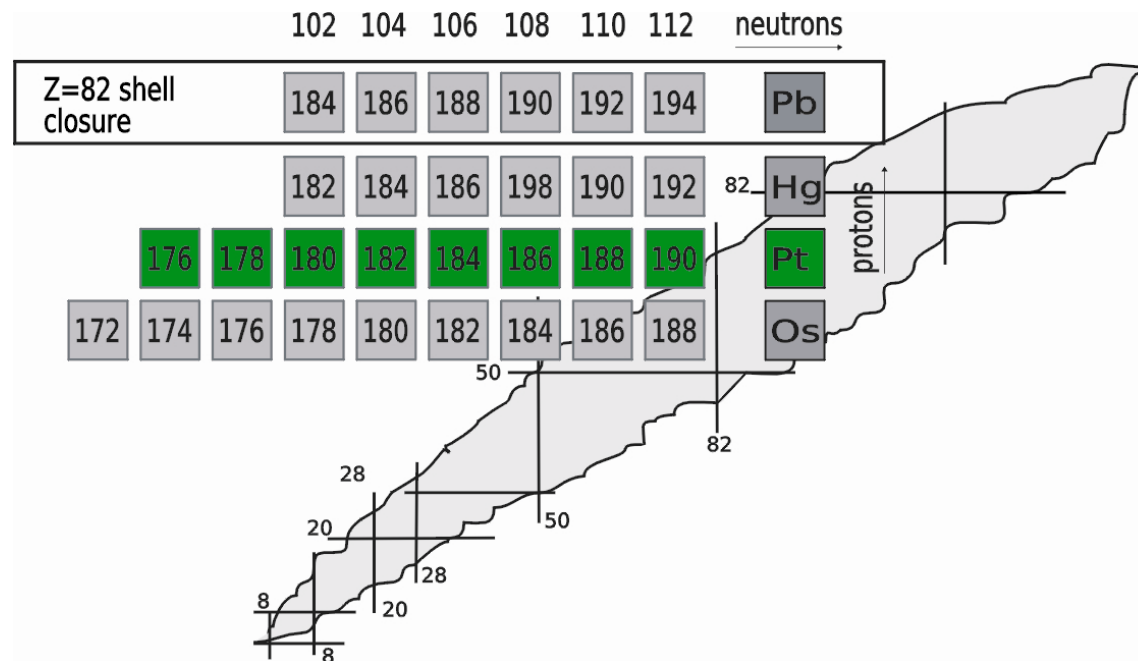
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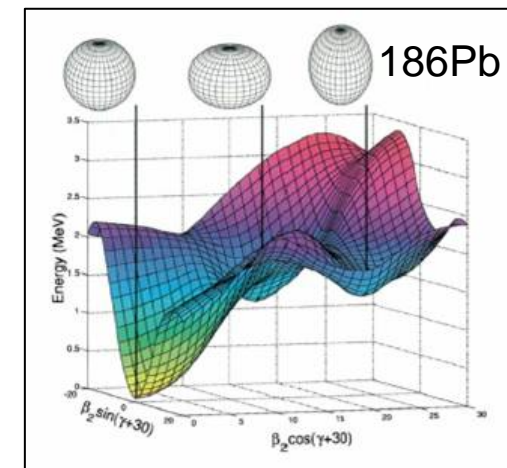
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1:: Introduction

Why the Pt isotopes?



The Z=82 region is 'famous' because of the occurrence of shape coexistence



A.N. Andreyev, *Nature*

- in the Pt-isotopes a sudden drop in the energy of the $0^+(2)$ state is observed around neutron midshell
- isotopic shift measurements display a sharp change in the nuclear charge radius
- is considered as a transitional region : transition from a prolate to an oblate minimum when going from lighter neutron-deficient Pt isotopes to the heavier ones.

2:: Mean-field calculations for the even Pt

Hartree-Fock method

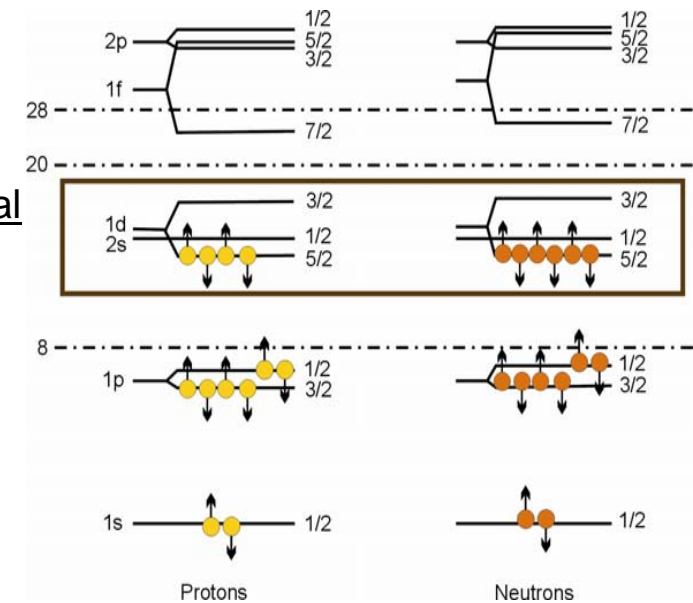
basic ideas : 1/ the success of the nuclear shell model justifies the assumption that the nucleons move fairly independently in an average potential

$$\hat{H}^{HF} = \sum_{i=1}^A \hat{h}(i)$$

$$|HF\rangle = \prod_{i=1}^A a_i^\dagger |-\rangle$$

2/ solving the Schrödinger equation $\hat{H}|\Psi\rangle = E|\Psi\rangle$

is equivalent to solving the variational equation



$$\delta \frac{\langle \Psi | \hat{H} | \Psi \rangle}{\langle \Psi | \Psi \rangle} = 0$$

HF equations are obtained when one obliges the wavefunction $|\Psi\rangle$ to be a Slater determinant during the variation $\delta \frac{\langle \Psi | \hat{H} | \Psi \rangle}{\langle \Psi | \Psi \rangle} = 0$

Hartree-Fock plus BCS

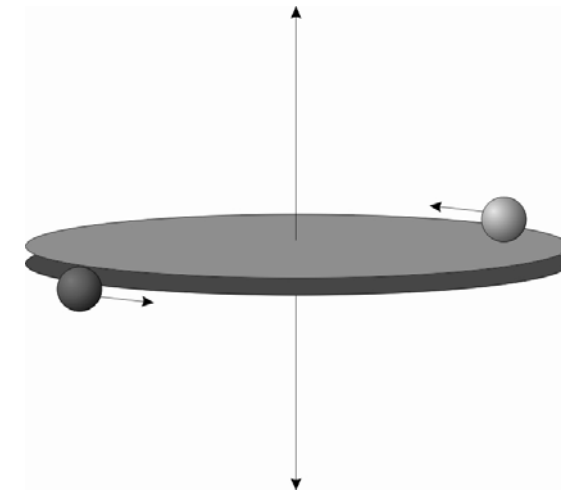
The pairing force

$$\hat{H}_{pair} = \sum_{k, k' > 0} \bar{v}_{k\bar{k}k'\bar{k}'} a_k^\dagger a_{\bar{k}}^\dagger a_{\bar{k}'} a_{k'}$$

$$|k\rangle \rightarrow |j, m\rangle$$

$$|\bar{k}\rangle \rightarrow |j, -m\rangle$$

energetically favours the coupling of two nucleons to J=0



For the description of **pairing between particles moving in different non-degenerate orbitals**, one introduces the **Bogoliubov quasi-particles**

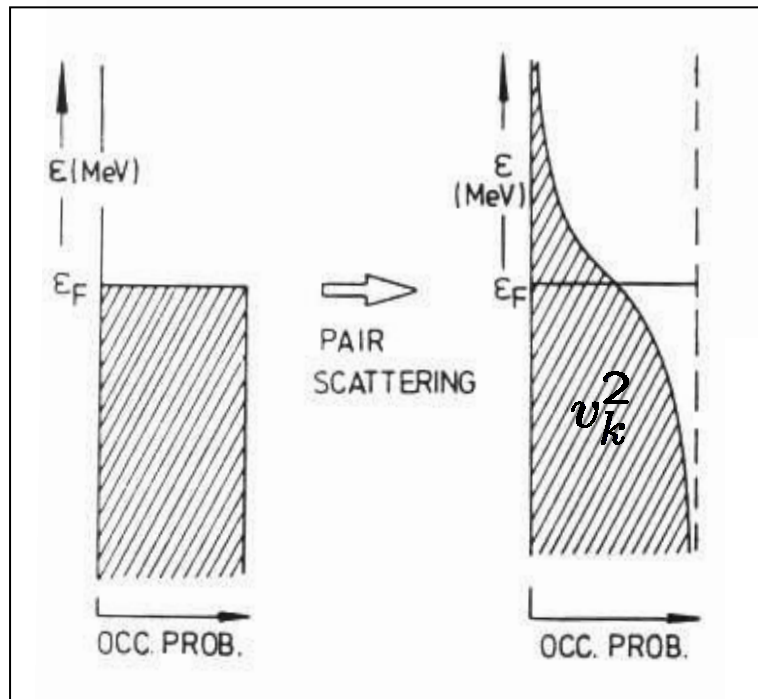
$$\alpha_k^\dagger = u_k a_k^\dagger - v_k a_{\bar{k}} \quad \alpha_{\bar{k}}^\dagger = u_k a_{\bar{k}}^\dagger + v_k a_k$$

$$\alpha_k^\dagger = u_k a_k^\dagger - v_k a_{\bar{k}}$$

$$\alpha_k = u_k a_k + v_k a_k^\dagger$$

- some properties of a hole, some properties of a particle
- transformation does not conserve particle number!!

→ wavefunction for even-even nuclei? $|BCS\rangle \propto \prod_k \alpha_k |-\rangle$



K. Heyde, The nuclear shell model

i.e. a gas of non-interacting quasiparticles

→ BCS equations follow from the variation of

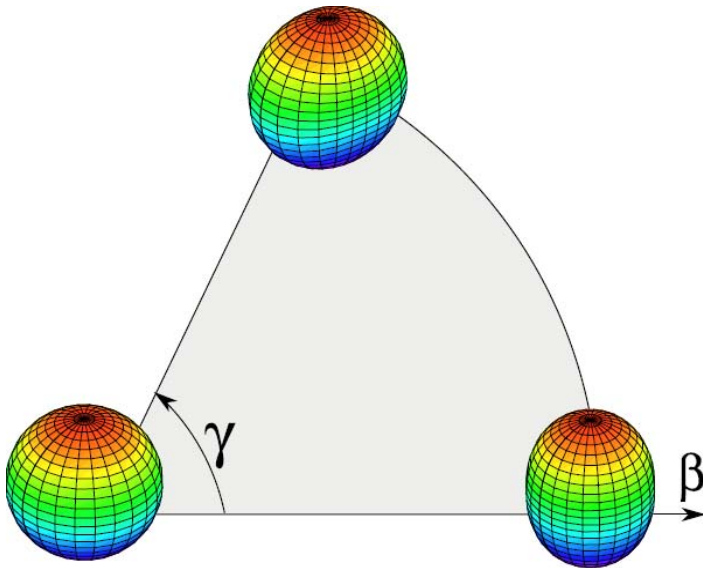
$$\langle BCS | \hat{H} - \lambda \hat{N} | BCS \rangle$$

enforce correct average particle number

Constrained HF +BCS

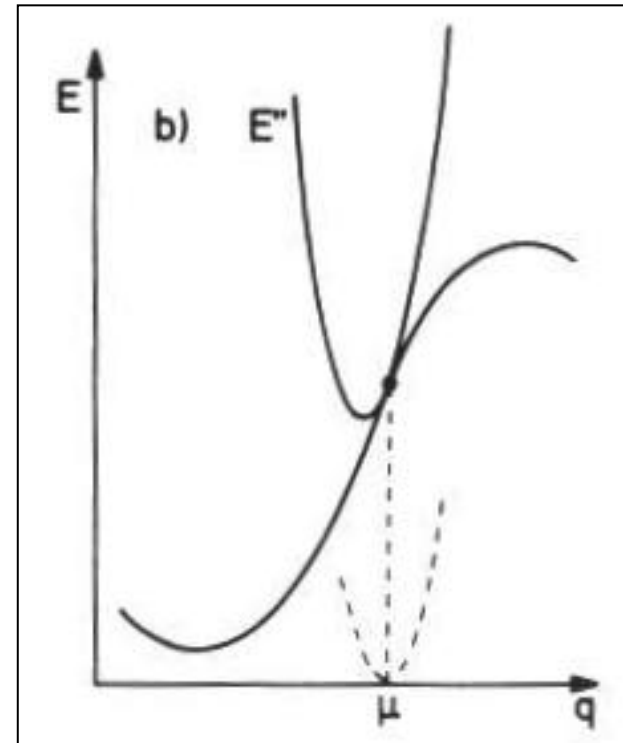
HF searches the minimum of the energy surface

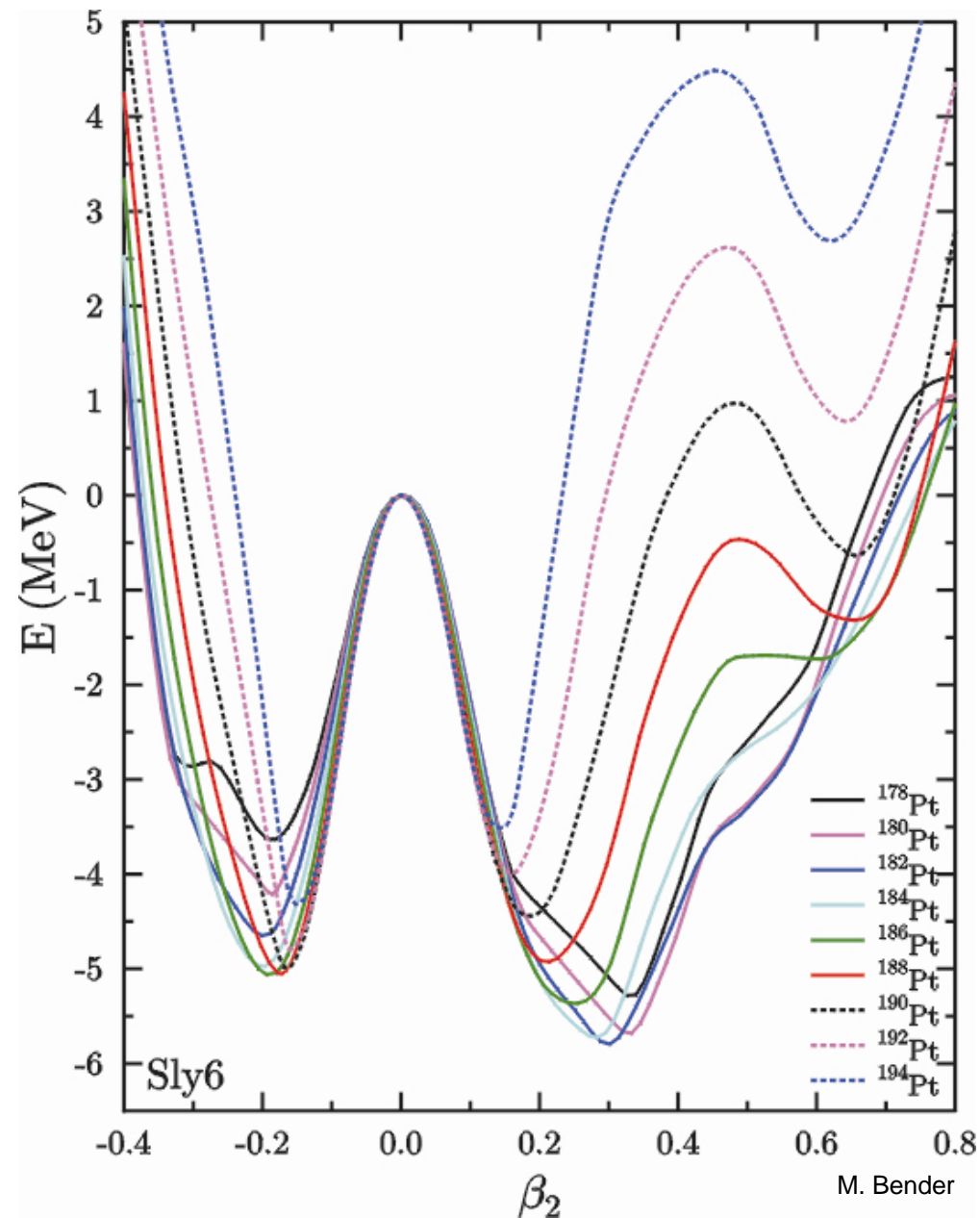
→ evolution of the energy with changing deformation?



- β axial quadrupole deformation
- γ non-axial quadrupole deformation

$$\langle \Psi | \hat{H}'' | \Psi \rangle = \langle \Psi | \hat{H} | \Psi \rangle + \frac{1}{2} C (\langle \Psi | \hat{Q} | \Psi \rangle - \mu)^2$$





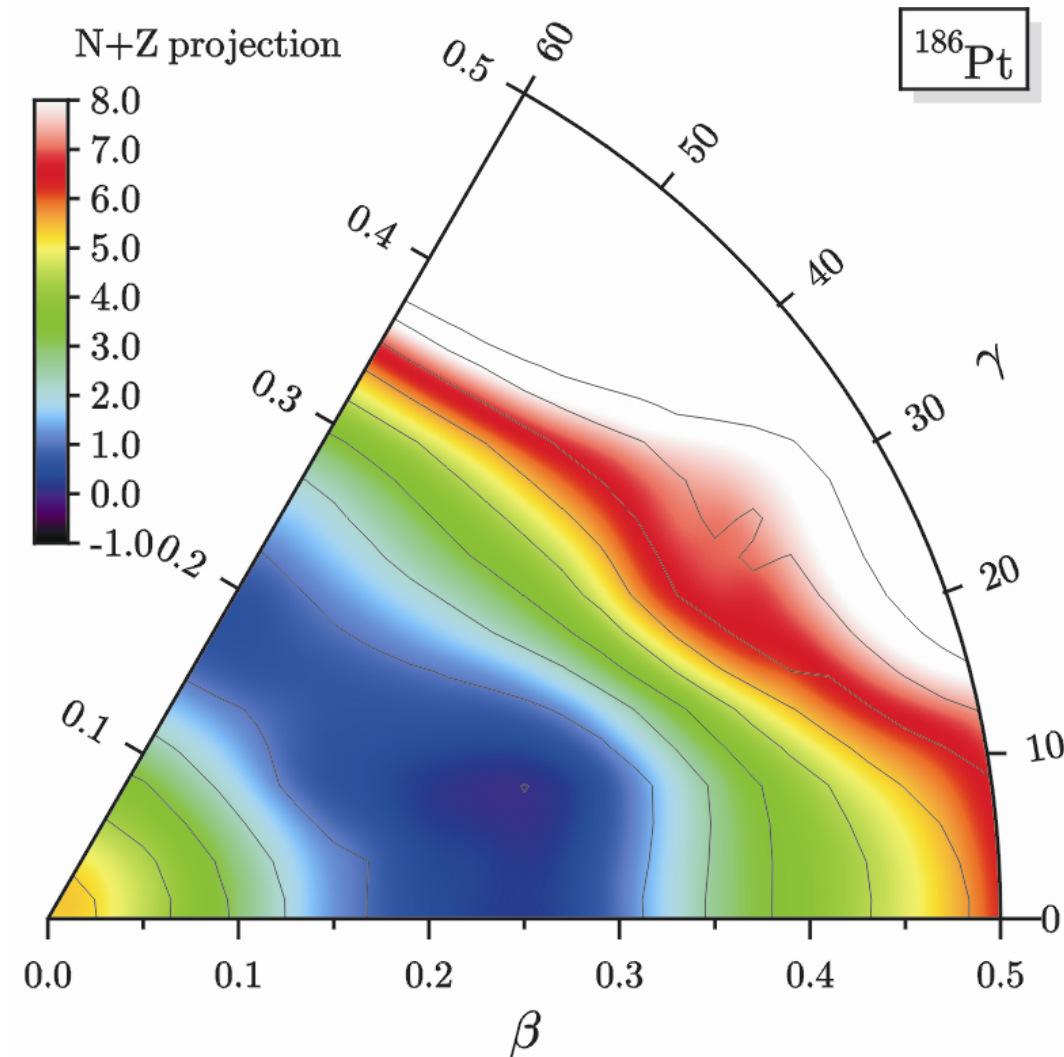
HF+BCS+LN

SLy6

pairing strength -1250 MeV

- transition from prolate to oblate minimum in the β direction with increasing N
- strongly deformed prolate minimum for the lighter Pt
- in ^{188}Pt , the minima are nearly degenerate

→ what about the γ -direction?

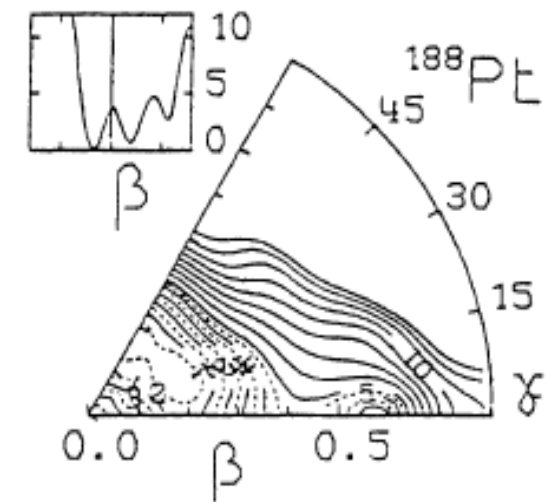


HF+BCS+LN

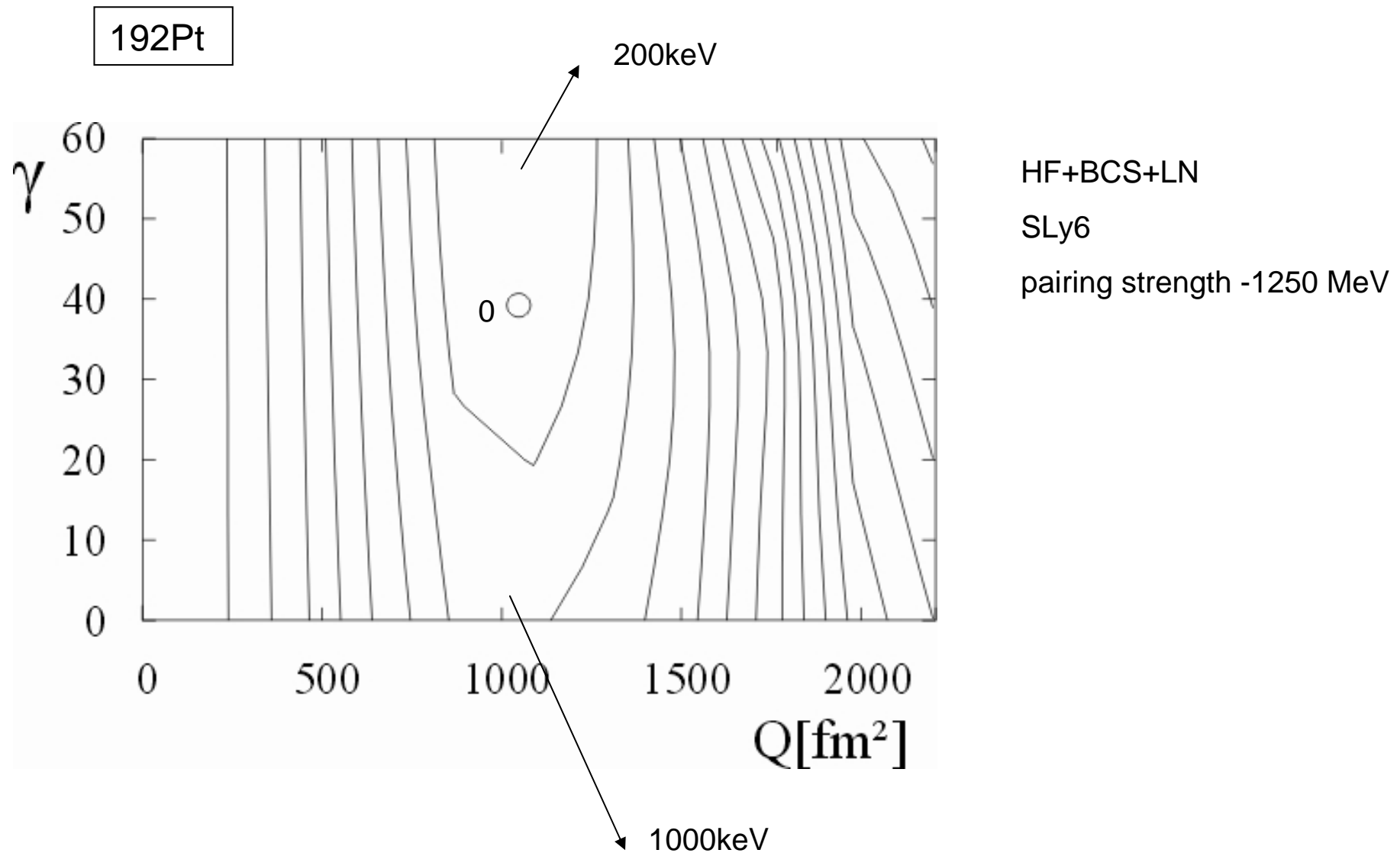
SLy6

pairing strength -1250 MeV

slightly triaxial minimum



M. Girod et al, PRL 62 (1989),2452



3:: Mean-field calculations for the odd Pt

Hartree-Fock + BCS

$$\alpha_k^\dagger = u_k a_k^\dagger - v_k a_{\bar{k}} \quad \text{quasi-particle}$$

$$|BCS\rangle \propto \prod_k \alpha_k |-\rangle$$

→ thus : the basic building blocks of the quasiparticle with quantumnumber k are the conjugate states k and \bar{k}

Hartree Fock Bogoliubov

natural extension of the BCS quasi-particles :

$$\beta_k^\dagger = \sum_l U_{lk} c_l^\dagger + V_{lk} c_l$$

transformation defined over all particle operators, NOT only the conjugate states

HFB equations follow from

$$\delta \frac{\langle \Phi | \hat{H} | \Phi \rangle}{\langle \Phi | \Phi \rangle} = 0$$

with $|\Phi\rangle = \prod_{k=1} \beta_k |-\rangle$

Odd nuclei ?

→ in HF+BCS odd nuclei can be described with one-quasiparticle excitations

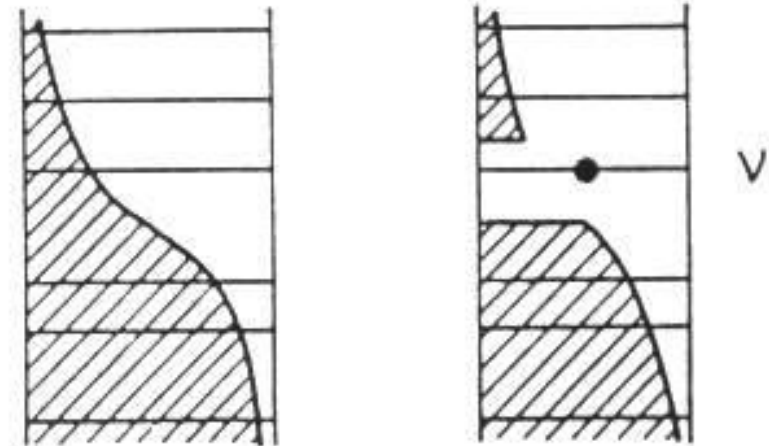
$$\alpha_{k_1}^\dagger |BCS\rangle = a_{k_1}^\dagger \prod_{k \neq k_1} \alpha_k |-\rangle$$

→ a certain single particle state is blocked

→ in HFB one quasi-particle states are defined similarly

$$|\Phi_l\rangle = \beta_l^\dagger |\Phi\rangle = \beta_l^\dagger \prod_k \beta_k |-\rangle$$

→ the structure of the blocked qp is more general than in BCS

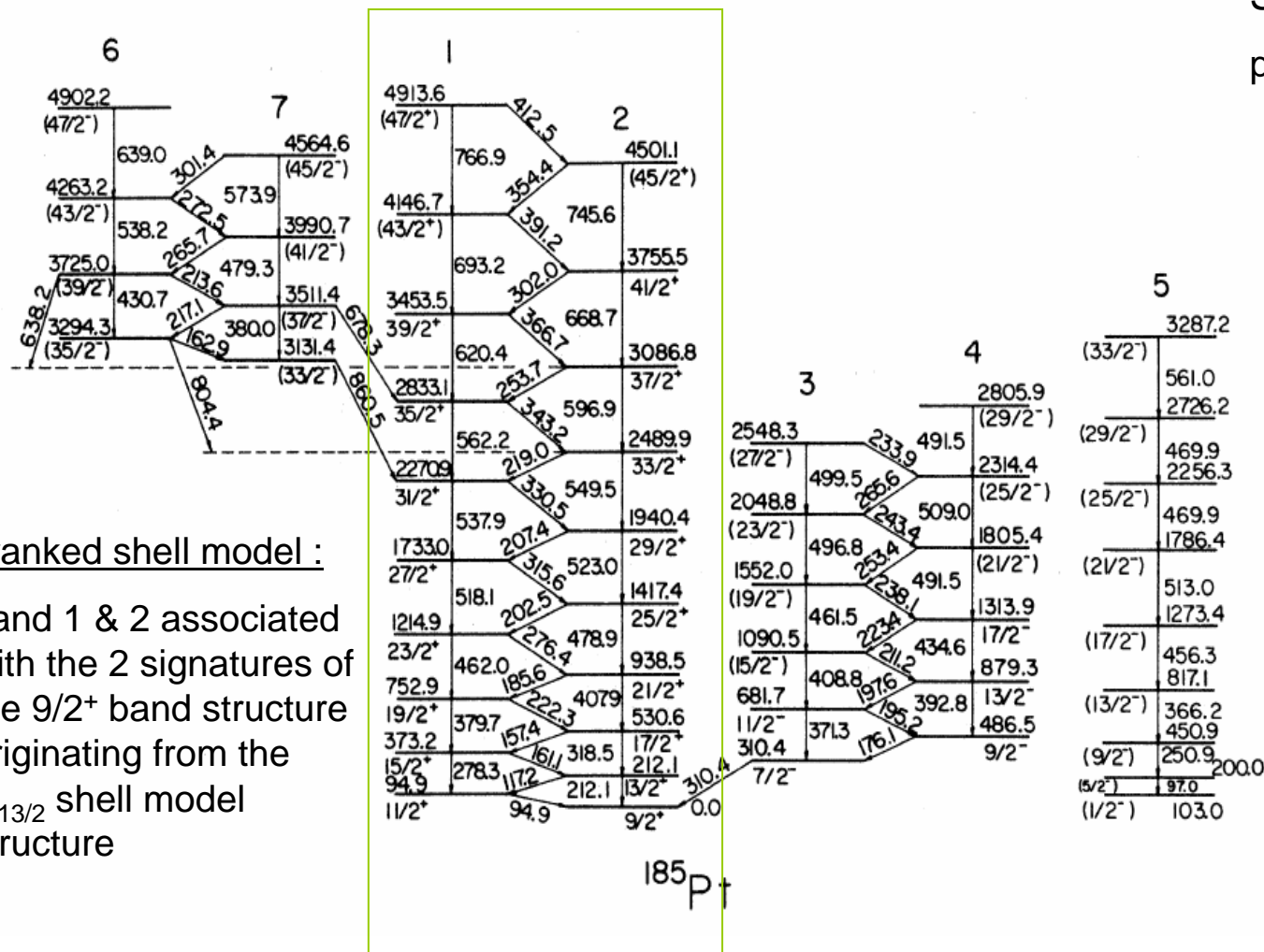


How do we introduce rotational motion?

variation with subsidiary condition that the angular momentum operator J_x has a certain expectation value (x-axis is not the symmetry axis)

$$\delta \langle \Phi | H - c(J_x - \bar{J}_x)^2 | \Phi \rangle = 0$$

185Pt



cranked shell model :

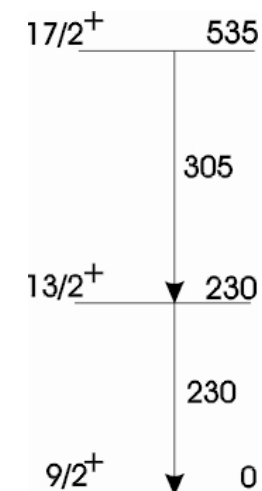
band 1 & 2 associated with the 2 signatures of the $9/2^+$ band structure originating from the $\nu_{13/2}$ shell model structure

HFB

SLy6

pairing strength -1250 MeV

1 neutron qp excitation (starting from ^{186}Pt) with prolate deformation and $K=-9/2$, parity +1 and signature -1



193Pt

HFB

SLy4

pairing strength -1250 MeV

PHYSICAL REVIEW C

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States in ^{193}Pt using the (p,t) reaction

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 (Received 16 April 1979)

goes to any other state. Thus the $\frac{1}{2}^-$ ground state of ^{193}Pt can be qualitatively identified as the band head of the $\frac{1}{2}^- | 530 |$ Nilsson state arising from an oblate potential with, however, considerable rotation-particle and vibration-rotation coupling. Reasonable but very tentative higher rotational members of the $\frac{1}{2}^- | 530 |$ band are the possible $\frac{3}{2}^-$ state at 188 keV and the $\frac{3}{2}^-$ or $\frac{5}{2}^-$ state at 232 keV assumed here to be $\frac{5}{2}^-$.

1 neutron qp excitation
 (starting from ^{192}Pt) with
 oblate deformation and $K=-$
 $1/2$, parity -1 and signature -1

→ with cranking, we obtain a
 $5/2^-$ state at 255 keV

experimental B.E. : 1531.218 MeV
 B.E. of $1/2^-$ state : 1527.850 MeV

4:: Outlook

- We have properly converged wavefunctions for some even and odd Pt-isotopes. These can be used as an starting point for other calculations in the Z=82 region, such as Hg, Po, Os, etc.

84	Po	Po 190 2,4 ms	Po 191 ~ 27 ms	Po 192 33,2 ms	Po 193 0,24 s	Po 194 0,45 s	Po 195 0,39 s	Po 196 1,9 s	Po 197 4,6 s	Po 198 5,8 s	Po 199 26 s	Po 200 56 s	Po 201 1,76 m
		α 7,529	α 7,330	α 7,167... γ (571); e ⁻	α 7,004	α 6,949	α 6,846 γ (658); e ⁻	α 6,699 γ (769); e ⁻	α 6,521... γ (769); e ⁻	α 6,389 γ (769); e ⁻	α 6,291 γ (769); e ⁻	α 6,185... γ (769); e ⁻	α 6,185... γ (769); e ⁻
Bi 187	Bi 188	Bi 189	Bi 190	Bi 191	Bi 192	Bi 193	Bi 194	Bi 195	Bi 196	Bi 197	Bi 198	Bi 199	Bi 200
8 ms	35 ms	44 ms	0,21 s	~ 5 ms	0,68 s	5,9 s	3,7 s	150 ms	12 s	40,6 s	34,6 s	3,2 s	87 s
α 7,586 γ 7,251 γ 7,251	α 7,396 γ 7,251 γ 7,251	α 7,221 γ 7,251 γ 7,251	α 7,052 γ 7,119 γ 7,119	α 6,886 γ 6,431 γ 6,431	α 6,720 γ 6,311 γ 6,311	α 6,554 γ 6,145 γ 6,145	α 6,389 γ 5,980 γ 5,980	α 6,221 γ 5,811 γ 5,811	α 6,054 γ 5,642 γ 5,642	α 5,886 γ 5,474 γ 5,474	α 5,719 γ 5,306 γ 5,306	α 5,551 γ 5,138 γ 5,138	α 5,384 γ 4,970 γ 4,970
Pb 186	Pb 187	Pb 188	Pb 189	Pb 190	Pb 191	Pb 192	Pb 193	Pb 194	Pb 195	Pb 196	Pb 197	Pb 198	Pb 199
4,8 s	18,3 s	15,2 s	18,3 s	1,2 m	2,2 m	1,4 m	5,6 m	4,0 m	12,0 m	15,0 m	~ 15 m	36,4 m	3,3 m
α 6,335 γ 6,335	α 6,168 γ 6,168	α 5,999 γ 5,999	α 5,830 γ 5,830	α 5,661 γ 5,661	α 5,492 γ 5,492	α 5,323 γ 5,323	α 5,154 γ 5,154	α 4,985 γ 4,985	α 4,816 γ 4,816	α 4,647 γ 4,647	α 4,478 γ 4,478	α 4,309 γ 4,309	α 4,140 γ 4,140
Tl 185	Tl 186	Tl 187	Tl 188	Tl 189	Tl 190	Tl 191	Tl 192	Tl 193	Tl 194	Tl 195	Tl 196	Tl 197	Tl 198
1,8 s	19,5 s	2,9 s	26,1 s	1,2 m	1,2 m	1,4 m	2,3 m	3,7 m	2,8 m	5,4 m	?	10,8 m	9,6 m
α 6,384 γ 6,384	α 6,215 γ 6,215	α 6,046 γ 6,046	α 5,877 γ 5,877	α 5,708 γ 5,708	α 5,539 γ 5,539	α 5,370 γ 5,370	α 5,201 γ 5,201	α 5,032 γ 5,032	α 4,863 γ 4,863	α 4,694 γ 4,694	α 4,525 γ 4,525	α 4,356 γ 4,356	α 4,187 γ 4,187
Hg 184	Hg 185	Hg 186	Hg 187	Hg 188	Hg 189	Hg 190	Hg 191	Hg 192	Hg 193	Hg 194	Hg 195	Hg 196	Hg 197
30,6 s	21 s	49 s	1,4 m	2,4 m	2,2 m	8,7 m	7,7 m	20,0 m	50,8 m	~ 50 m	11,1 h	3,5 h	520 a
α 5,54 γ 5,54	α 5,37 γ 5,37	α 5,20 γ 5,20	α 5,03 γ 5,03	α 4,86 γ 4,86	α 4,69 γ 4,69	α 4,52 γ 4,52	α 4,35 γ 4,35	α 4,18 γ 4,18	α 4,01 γ 4,01	α 3,84 γ 3,84	α 3,67 γ 3,67	α 3,50 γ 3,50	α 3,33 γ 3,33

- Include the tensor part of the skyrme interaction in the HFB+ cranking code
- Study the effect of the time-odd components in the skyrme energy density functional